Vacuum Attachment Mechanism

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LONG-TERM GOAL

The long-term goal of this work is to improve the underwater warfare operational capabilities. Attachment of objects to underwater surfaces is a critical part of naval warfare and this can be accomplished by means of adhesive systems, magnetic force systems, mechanical attachments and vacuum attachments. The use of vacuum attachment mechanisms can improve operational capabilities by simplifying the deployment operation, decreasing the on-target time, reducing attachment surface selectivity, and reducing detection risks. Impovements of these operational capabilities would also lead to an improvement of diver-soldier safety during system deployment.

OBJECTIVES

The objective of this project is the development of a device for the attachment of payloads to unspecified underwater surfaces. Focus of this development effort is on a system that utilizes the suction force created by a vacuum (pressure differential) to establish an attachment platform to underwater surfaces. Using a vacuum attachment mechanim, rather than mechanical or magnetic attachment, allows for the attachment of payloads to surfaces without any restrictions on the type of surface and the surface roughness or preparation. System development consists of optimizing subsystems as well as design, construction and evaluation of prototypes in realistic underwater conditions. At the conclusion of this project a production ready, vacuum attachment system design and prototype will be delivered to the client.

APPROACH

A systems engineering approach is used for the development of the vacuum attachment device. The system operational requirements are obtained from the client and these requirements are used to guide guide the generation of concepts for the different device components. Device components include the vacuum seal or suction cup, vacuum generation mechanism, and supporting structure (that is also used for payload attachment). After a down selection process the selected concepts are analyzed and developed to a higher level of detail to enable prototype testing of the different components. Commercially-of-the-shelf (COTS) components are the components of choice, and in-house component development is only considered if no feasible COTS system exist. Individual components of the system are then evaluated in both laboratory and field testing to ensure that the system requirements are satisfied. Once technical feasibility of all components have been proven the components are integrated into a device that is fabricated and tested. A second device fabrication iteration is completed to incorporate impovements from the initial evaluation cycle. This device and all associated documentation are the deliverables for this project. The project is being completed by the principal investigator and Mr. A.J. du Plessis and Mr. L.E. Breaux.

WORK COMPLETED

The most generally defined vacuum attachment device must have at least the following components: vacuum chamber with a sealing interface, vacuum generation system, and a support structure. The initial project task completed was generating and evaluating concepts for the chamber and sealing interface. At the start of the project it was assumed that COTS suction cups were available that would satisfy the curvature and surface roughness requirements of the application. A study of COTS suction cups was completed and no cups were identified that satisfy the technical requirements. As a result of the COTS study a number of alternative suction cup concepts were generated and evaluated. The most promising concept was the "*in-situ*" molded suction cup (IMSC). A schematic of the IMSC is shown in Figure 1. For this system uncured polymer material is injected into a suction cup mold under the surface of the water and the mold pressed onto the attachment surface. The uncured material deforms exactly to the irregular surface shape and cures in this shape. Once the material has cured the vacuum can be applied to the device. This concept allows for the attachment to surfaces of any shape, roughness and kind. The disadvantages of the system are the underwater mixing requirement, the time it takes for the polymer to cure, the temperature dependance of the curing reaction, and no reset capability if the vacuum seal fails. The IMSC concept is a high technological risk concept because the polymer material system is unspecified and no similar COTS systems exist. Possible technical success of the IMSC concept negated the technological risk and this concept was chosen for further analysis and development.

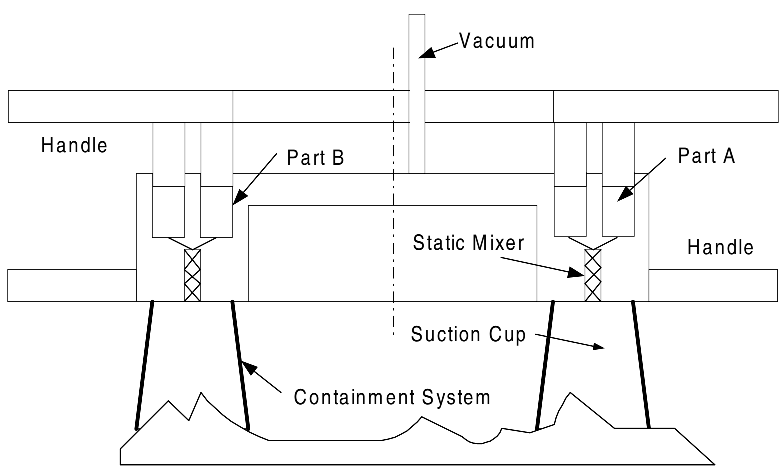

Figure 1. In-situ molded suction cup concept with integrated mixing of molding polymer.

The support structure of the device is not a very complex system and only provides for mounting of the vacuum generation system, and suction cup as well as the attachment point of the payload. It was decided to integrate the polymer mixing system into the support structure (as is shown in Figure 1). The combined structure and IMSC system, including the mixing and containment system, were analyzed, modeled and developed to a sufficient level to allow for prototype testing. A model of the prototpye device is shown in Figure 2. Results of the laboratory testing and field testing is presented in the results section.

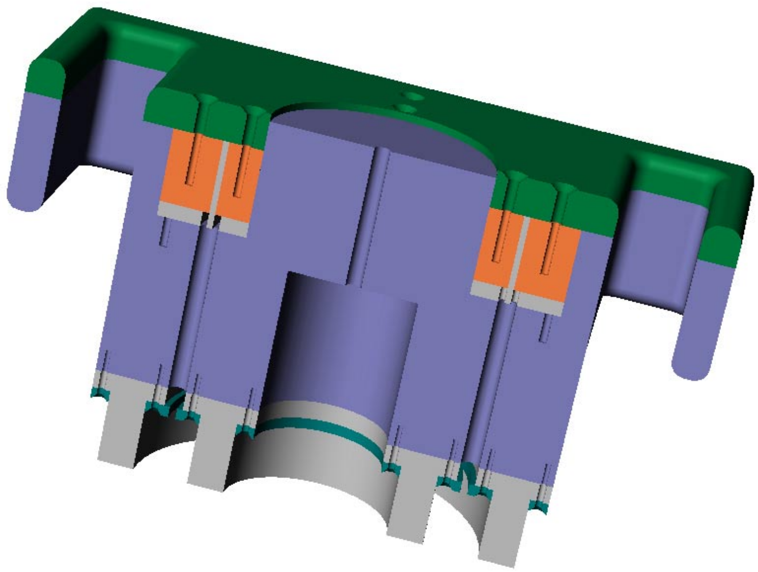

Figure 2. Model of in-situ molded suction cup and support structure.

The other major component of the device is the vacuum generation mechanism. The following candidate systems were identified as possible vacuum generation mechanisms:

- Volumetric changes in hydrogels,
- Solution of gasses into liquid solvents, and
- Mechanical vacuum generation.

Gels are substances made up of very long polymer strands that are immersed in a liquid medium. The properties of a gel strongly depend on the interaction of the polymer and solution. Some of the interesting characteristics of gels is that drastic changes of gel properties can be affected by changing the external conditions to which a gel is exposed, such matrix volume with varying temperature [Tanaka, 1981] and applied electrical field [Shahinpoor, 1995]. This volumetric change can be used to generate a vacuum. Another group of candidate vacuum generation mechanisms is the solution of gasses into liquid solvents. When gasses, such as carbon dioxide and ammonia, are dissolved into water in a closed system a drop in pressure is observed inside the closed system. This pressure drop can also be used to generate a vacuum. The last group of vacuum generation mechanisms are mechanical mechanisms. A number of concepts, models and prototypes, that utilizes the different generation mechanisms, were generated, developed and tested to determine the most appropriate vacuum generation system for the attachment device. The result from this analysis indicated that the reciprocating fluid pump is the best vacuum generation mechanism for the underwater application, and such systems are available COTS.

RESULTS

The most important results of this development project is the prototype test results. Initial testing of the ISMC concept was done in a laboratory environment by generating a vacuum on a flat plastic surface with pyramids machined into the surface. Results of this test is shown in Figure 3. The importance of this results is prove of the feasibility of using an IMSC to form a suction cup on a very irregular surface. It should be noted that this test did not include the mixing subsystem.

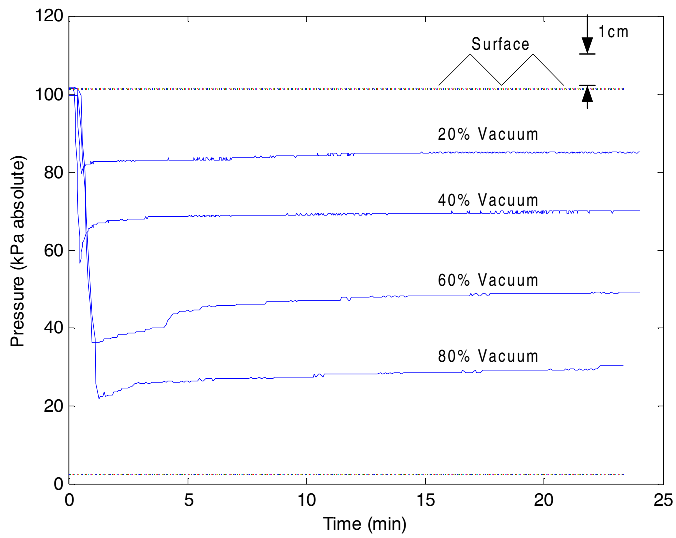

Figure 3. Vacuum testing of IMSC prototype on flat plastic plate with pyramids on the surface.

The second part of the prototype evaluation consisted of field testing the device (shown in Figure 2) on real underwater marine surfaces. Device evaluation included mixing and delivery of the molding polymer into the cup mold, establishing a seal against the marine surface, curing of polymer in a short period of time, and establishing and maintaining a vacuum. The prototype did not perform to expectations and failed this evaluation. A picture of the underwater cured suction cup is shown in Figure 4.

Figure 4. Suction cup of IMSC prototype after testing on real underwater marine surface.

It is clear from the evaluations that the IMSC concept is a feasible concept, but a number of technical issues need to be resolved for this approach to be successful. Technical problem areas include the mixing system, packaging volumetrics, polymer formulation, and the ability to reset the system if a vacuum can not be established on the first attempt. Based on the results of the evaluation it was decided to take a lower risk approach by directing all future project efforts to develop a device that incorporates pre-cured COTS suction cups and other COTS components. The surface roughness requirements for the device have been relaxed to make this new approach feasible.

IMPACT/APPLICATION

The vacuum attachment device is a non-electrical, non-magnetic, non-adhesive underwater attachment system that can attach to underwater surfaces made of any non-porous material, without any surface preparation, in a very short period of time. This system will find wide application in underwater intelligence and demolition missions. Other military applications include attachment of payloads on surfaces where typical attachment schemes such as magnetics will lead to detection. Commercial applications include marine research programs, such as attaching sensors to marine mammals. Another commercial application is for underwater salvage operations where surface damage should be minimized, such as the case of salvaging historic boats.

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